Analog Electronic Circuits
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Lecture - 32
Common Source Amplifier (Part A)

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NPTEL ONLINE CERTIFICATION COURSES

Course Name: *Analog Electronic Circuits*
Faculty Name: *Dr. Pradip Mandal*
Department : *Electronics and Electrical Communication Engineering*

Topic:
Common Source Amplifier

So, dear students so we welcome to this NPTEL course on Analog Electronic Circuits, myself Pradip Mandal from E and EC department of IIT Kharagpur. So, today the module will be discussing it is Common Source Amplifier and it is it is another basic amplifier along with the common emitter amplifier.

So, lot of similarities are there with respect to common emitter amplifier and common source amplifier. However, it is different also and if you move forward particularly towards the micro electronics design and analog micro electronics design where instead of BJT MOSFET is quite popular. So, this common source amplifier is plays a very important role.

So, whatever the concepts it will be covered here you need to be very careful in case if you are planning for micro electronics and VLSI design particularly in the area of analog.

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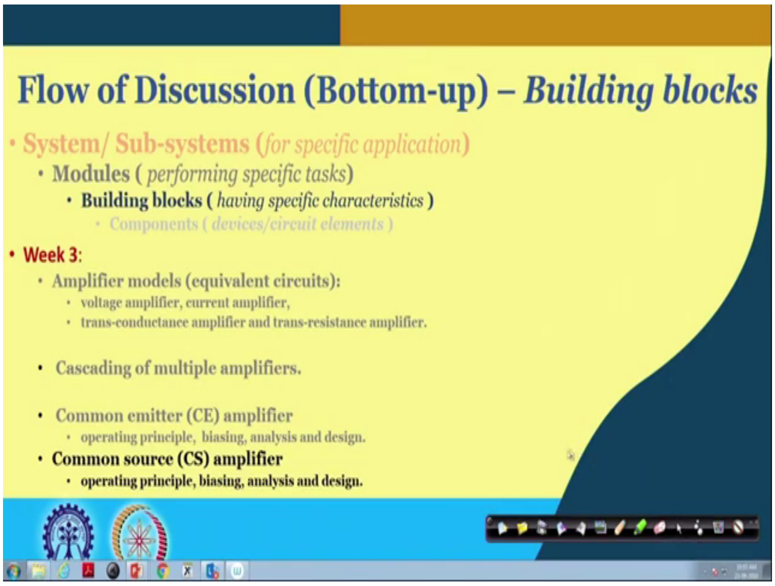

Flow of Discussion (Bottom-up) – *Building blocks*

- System/ Sub-systems (*for specific application*)
  - Modules (*performing specific tasks*)
    - **Building blocks** (*having specific characteristics*)
      - Components (*devices/circuit elements*)
- Week 3:
  - Amplifier models (equivalent circuits):
    - voltage amplifier, current amplifier,
    - trans-conductance amplifier and trans-resistance amplifier.
  - Cascading of multiple amplifiers.
  - Common emitter (CE) amplifier
    - operating principle, biasing, analysis and design.
  - **Common source (CS) amplifier**
    - **operating principle, biasing, analysis and design.**

So, in terms of our overall plan today we are in the third week's module and we are towards the end of it. So, what we have in our plan it is the common source amplifier we will start with the basic operation. Some extent we have covered before, but in the present context we may have to recapitulate. And then most important thing is that the biasing, analysis and some numerical examples and some design guidelines.

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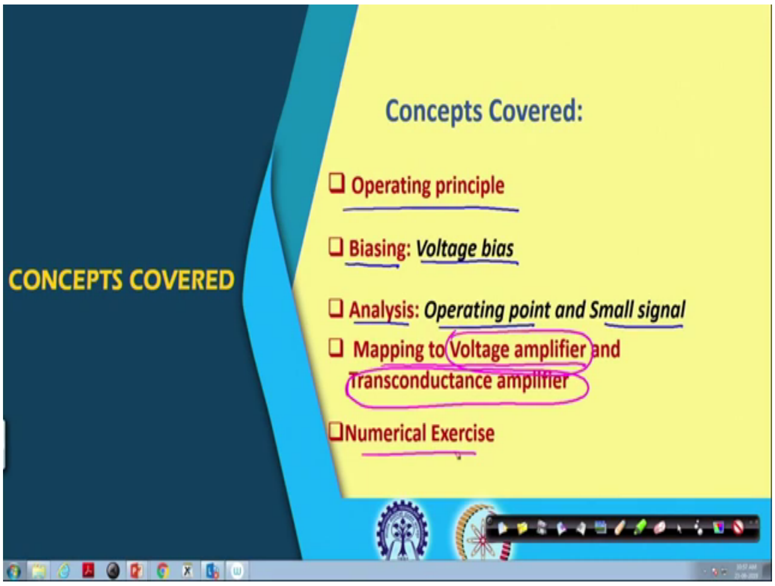

CONCEPTS COVERED

Concepts Covered:

- ☐ Operating principle
- ☐ Biasing: *Voltage bias*
- ☐ Analysis: *Operating point and Small signal*
- ☐ Mapping to Voltage amplifier and Transconductance amplifier
- ☐ Numerical Exercise

So, whatever the concepts we will be covering today it is as I say that we will start with the basic operating principle of common source amplifier and then biasing since the bias we do we are the gate and at the gate terminal the corresponding current is 0. So, at the base sorry gate the bias need to be voltage. So, that is why voltage bias it will be used at the gate.

And then analysis; analysis it will be having 2 parts one is for DC finding DC operating point and the small signal analysis. And the amplifier in this case particularly for common source amplifier typically it is mapped on a voltage amplifier as the input it is input signal need to be voltage at the gate, but at the output the signal can be either voltage or current.

So, if the output signal it is voltage then the corresponding amplifier it is voltage amplifier. On the other hand at the output in case if we are detecting the signal in the form of current, then the corresponding amplifier common source amplifier can be treated as trans conductance amplifier and then of course, we will be covering some numerical exercise.

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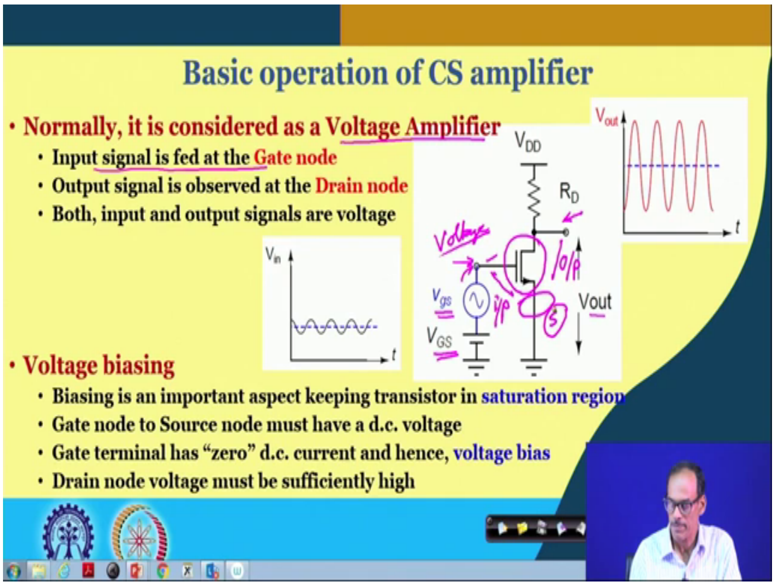

Basic operation of CS amplifier

- Normally, it is considered as a Voltage Amplifier
  - Input signal is fed at the Gate node
  - Output signal is observed at the Drain node
  - Both, input and output signals are voltage
- Voltage biasing
  - Biasing is an important aspect keeping transistor in saturation region
  - Gate node to Source node must have a d.c. voltage
  - Gate terminal has “zero” d.c. current and hence, voltage bias
  - Drain node voltage must be sufficiently high

Now, the circuit wise you can see here this is the basic common node structure of the common source amplified. We do have the MOSFET here and at the gate we are applying a voltage. So, it is having the DC part along with the signal part and as I said that normally it is considered as voltage amplifier. So, which means that the signal at the gate it is voltage and the output of course, the signal can be either voltage or current and so we will be discussing now at least the output signal in the form of voltage. So, we call it is voltage amplifier.

So, the input has received that input signal it is basically we are feeding at the gate and we observe the output at the drain and hence the source terminal it is common for both input port and the output port.

So, that is why we call this structure it is common source amplifiers. So, the source terminal it is common for both the ports. So, that is why you call it is common source amplifier now the biasing aspect for this circuit it is as I said that it is voltage bias in nature and yeah.

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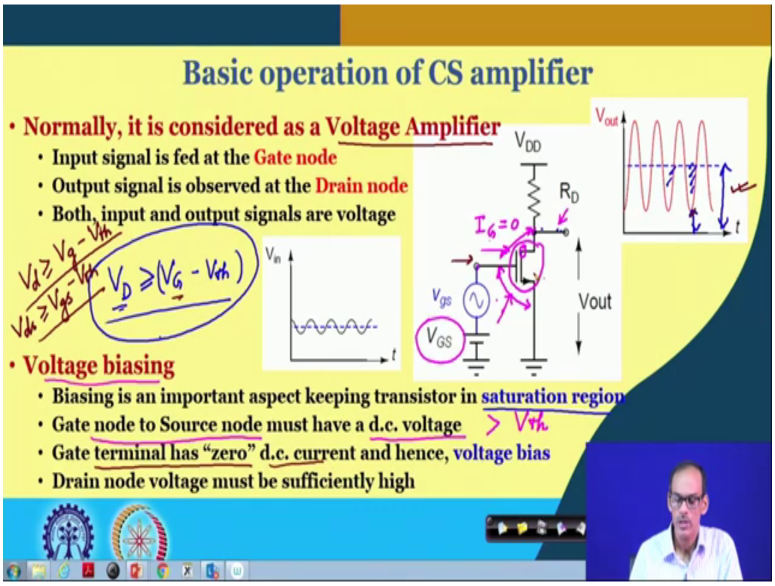

Basic operation of CS amplifier

- **Normally, it is considered as a Voltage Amplifier**
  - Input signal is fed at the Gate node
  - Output signal is observed at the Drain node
  - Both, input and output signals are voltage

$V_d \geq V_g - V_{th}$

$V_{ds} \geq V_{gs} - V_{th}$

$V_D \geq (V_G - V_{th})$

- **Voltage biasing**
  - Biasing is an important aspect keeping transistor in saturation region
  - Gate node to Source node must have a d.c. voltage $> V_{th}$
  - Gate terminal has "zero" d.c. current and hence, voltage bias
  - Drain node voltage must be sufficiently high

So, as I say that the biasing at least at the gate need to be voltage because the DC current here if I say that I capital G that is equal to 0. So, the gate voltage need to be sufficiently high and while you are keeping this gate voltage connected from a signal source we assume that the gate current is 0 which is practically the case. Now, most of the time we will be dealing with this device which is called enhancement mode device to turn it on we require a DC voltage at the gate with respect to source.

So, we say that this V GS this voltage we required so that the device is on and typically this voltage should be few hundred or maybe even a few volts higher than threshold voltage of the device. So, gate to source node voltage; gate to source node voltage should be having a positive DC to keep the device on. Not only positive DC it should be higher than threshold voltage of the transistor.

On the other hand the gate voltage it should be sufficiently high so that; so that the this terminal and the drain trump terminal with respect to gate it satisfies the condition. So, that the pinch of it is happening at the drain end or to be more precise the gate voltage or other drain voltage should be higher than gate voltage minus V th. So, we need to satisfy this condition not only for DC, but also whenever the signal it is present there.

So, the DC voltage that the drain it should be sufficiently high. So, that even if you have the signal; even if you have the signal at least this minimum voltage at the drain which is incidentally this is output voltage it should be sufficiently high and satisfying this condition. So, to keep the device in saturation region we require this condition we may keep this equal to also.

So, in fact to be more precise and not only the DC voltage ah, but also the instantaneous voltage. So, I should say that capital V small d should be higher than or equal to the gate voltage which may be having the DC part as well as the signal part and then this condition need to be satisfied or we can say that V ds same source is common. We can write V ds should be higher than V gs minus V th.

So, the role of keeping this output voltage that is DC voltage sufficiently high, so that the transistor remains in saturation. And as I said that the gate terminal current so this terminal current has DC current so the biasing here you need to be voltage. So, we will be discussing little detail of the practical circuit, but just before going to the practical circuit as I say that we like to treat this circuit as a voltage amplifier and which means that this circuit we need to map into a voltage amplifier model. So, we have discussed that voltage amplifier model.

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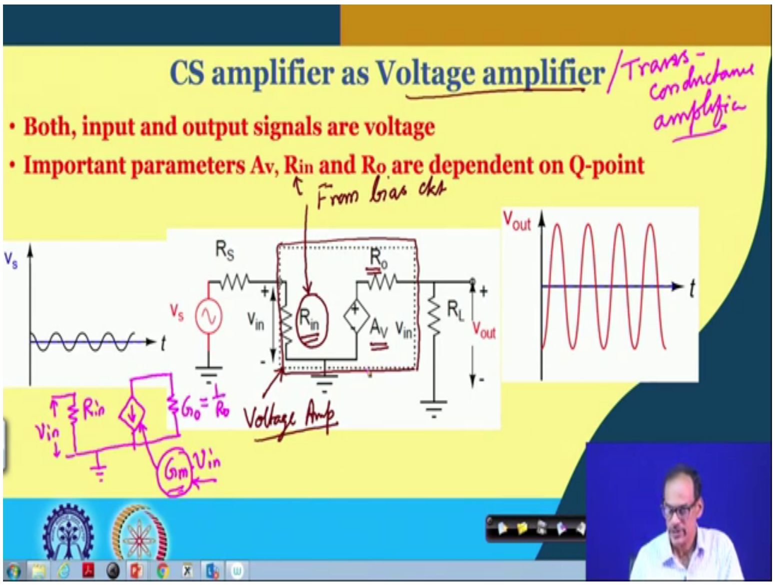

CS amplifier as Voltage amplifier / Trans-conductance amplifier

- Both, input and output signals are voltage
- Important parameters A_V, R_{in} and R_o are dependent on Q-point

So, similar to common emitter amplifier here the model here it is given. So, this is the voltage amplifier. So, in case if it is voltage amplifier we do have 3 important parameters the voltage gain, then output resistance and input resistance and so these are the 3 important parameters and as I said that gate terminal for the main device the current is 0. So, typically this V in it is coming from the bias circuit. So, the source of this V in or this V in, it is basically from bias circuit and the so yeah.

So, the small signal equivalent circuit it will be mapped into this model in case if we like to treat as voltage amplifier. On the other hand in case if you are looking to map for map this amplifier into say transconductance amplifier where the output we like to treat as current. So, in case if you are looking for transconductance amplifier; transconductance amplifier. So, in that case this port it will be different.

So, what will be the corresponding model? At the input we do have the R in and at the output port will be having voltage dependent current source. So, we may keep this polarity in this direction or whatever the direction you would like to put as convention and then we do have the output conductance. So, that is say G naught equals to 1 by R naught and the voltage dependent current source it is G m trans conductance of the circuit multiplied by the input voltage and the input voltage it is the voltage across this R in. So, that is what the transconductance model.

So, this is a course it is again it depends on whatever the G m of the device it is there, but it is the overall trans conductance G m. So, we will be coming back to this mapping into this voltage amplifier model or transconductance amplifier model, but let me see the practical circuit and as I said that and this.

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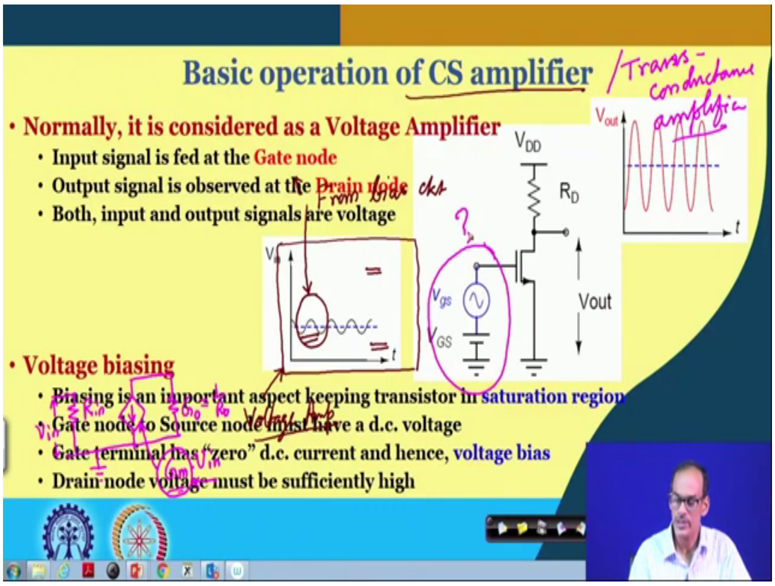

Basic operation of CS amplifier /Trans-conductance amplifier

- **Normally, it is considered as a Voltage Amplifier**
  - Input signal is fed at the Gate node
  - Output signal is observed at the Drain node
  - Both, input and output signals are voltage
- **Voltage biasing**
  - Biasing is an important aspect keeping transistor in saturation region
  - Gate node to Source node must have a d.c. voltage
  - Gate terminal has "zero" d.c. current and hence, voltage bias
  - Drain node voltage must be sufficiently high

Yeah, so we are going to look into the practical circuit how we generate this bias. So, whatever the bias circuit we are discussing here we like to see what kind of practical circuit will be having.

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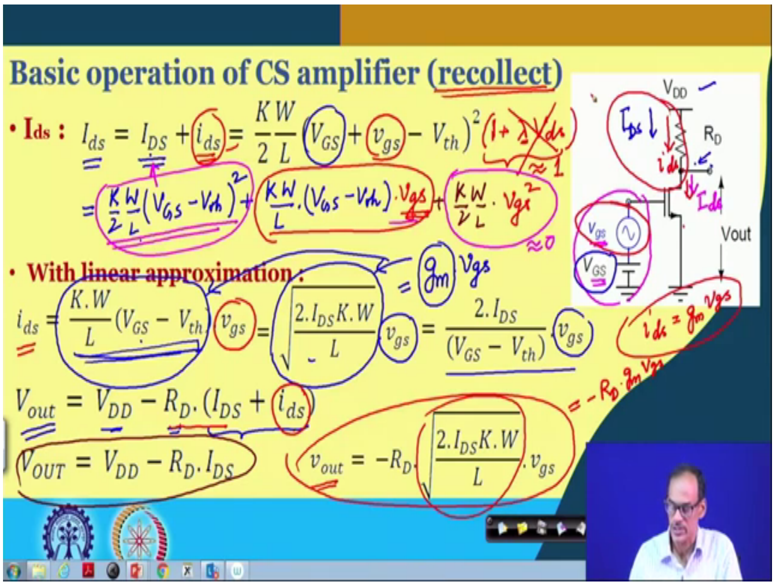

Basic operation of CS amplifier (recollect)

- **Ids :** $I_{ds} = I_{DS} + i_{ds} = \frac{K}{2}\frac{W}{L}(V_{GS} + v_{gs} - V_{th})^2(1+\cancel{\lambda V_{ds}})$ ≈ 1

$$= \frac{K}{2}\frac{W}{L}(V_{GS}-V_{th})^2 + \frac{KW}{L}.(V_{GS}-V_{th}).v_{gs} + \frac{K}{2}\frac{W}{L}.v_{gs}^2 \quad \approx 0$$

- **With linear approximation :**

$$i_{ds} = \frac{K.W}{L}(V_{GS} - V_{th})v_{gs} = \sqrt{\frac{2.I_{DS}K.W}{L}}v_{gs} = \frac{2.I_{DS}}{(V_{GS} - V_{th})}v_{gs}$$

$= g_m v_{gs}$

$$V_{out} = V_{DD} - R_D.(I_{DS} + i_{ds})$$

$$V_{OUT} = V_{DD} - R_D.I_{DS} \qquad v_{out} = -R_D\sqrt{\frac{2.I_{DS}K.W}{L}}.v_{gs} = -R_D.g_m v_{gs}$$

$i_{ds} = g_m v_{gs}$

Now, let me go to the practical circuit yeah. What we have before we go into the in fact, we do have the practical circuit in the next slide yeah. So, we will be discussing this practical circuit, but before that let me this recapitulate what we have covered before namely the analysis of this circuit.

So, what we are doing here it is at the gate we are applying a DC in combination with a small signal and then that is defining the output port current. So, this current we call capital I small d s and this I ds it is having 2 parts. So, the I ds it is having the DC part which is coming from the this DC and also it is having AC part this ac part which is due to that this is AC signal.

And if you see the device characteristic equation we have discussed before which is K divided by 2 W by L of the transistor multiplied by v gs minus V th squared.

Now here of course, we are ignoring this one plus lambda V ds part. So, we are assuming that this part is approximately equal to 1 or namely this lambda it is so small we are approximating this one that is fair enough in this case later we may have to consider that term also, but for the time being let me draw this part. And then as I say that it is the V gs which is from outside we are giving which is having the small signal part and then also it is having the DC part we do have the DC part.

So, if we rewrite this equation we can get 2 parts one is the K by 2 W by L V gs minus V th squared which is independent of the small signal part and then also we do have K W by L into V GS minus V th into small v gs into small v gs then plus we still have one more term it which is K by 2 W by L into v gs v gs square part. And if we approximate if we ignored this equation the second order term in this equation namely this part compared to this linear part.

So, we are dropping this part to 0 by comparing the linear term, then what we have it is the DC part and then the small signal part. So, this is the DC part which is representing this DC part independent of the small signal. On the other hand we do have the AC part. So, we do have this part is the AC signal.

So, we can say that this signal part AC part it is the function the current signal it is function of the voltage signal at the input or we can say that this small I ds it is a function of the input voltage and the remaining part of this expression it is function of the DC part. In fact, if I consider the expression of I ds is given here this term the only the DC dependent part can be rewritten in this form typically one of these 2 forms it is used. In fact, we do have the third expression also, so, but either this one or this one it is used multiplied by of course, this v gs.

So, we can say that I ds equals to this part which is referred as transconductance into v gs and this g m transconductance of the device it is this one or it may be in this one either form it is fine. So, both are representing the transconductance of the circuit. So, which means that the small signal current at the I ds here it is actually I should say I ds in short form we can say that gm into v gs in the linear form and then we do have the DC part.

So, as I said that the both these currents are flowing from drain to source and both the components are flowing through this R D. So, we do have small i ds and also we do have the DC part namely capital I ds as a result we do have a voltage here which is V DD minus this drop. So, the output voltage; output voltage it is having an expression this V DD minus R D multiplied by the total current. And in the total current as I said that it is having DC part as well as the small signal part.

So, if I multiply these 2 terms what we are getting here it is the DC expression of the output voltage and then the remaining part namely minus R D into I ds that gives us the small signal part. And this is by the definition of this g m here it is or the expression of the gm here it is minus R D into g m into V gs ok, so that is the V out.

So, as I said that this part we have discussed earlier. So, we considered this discussion actually recollection of whatever we already have discussed before in different form, but anyway this analysis or this discussion it will be used in the practical circuit. So, please keep this in mind that the I ds it is having 2 parts one is the DC and small signal part. Small signal part it is g m into v gs.

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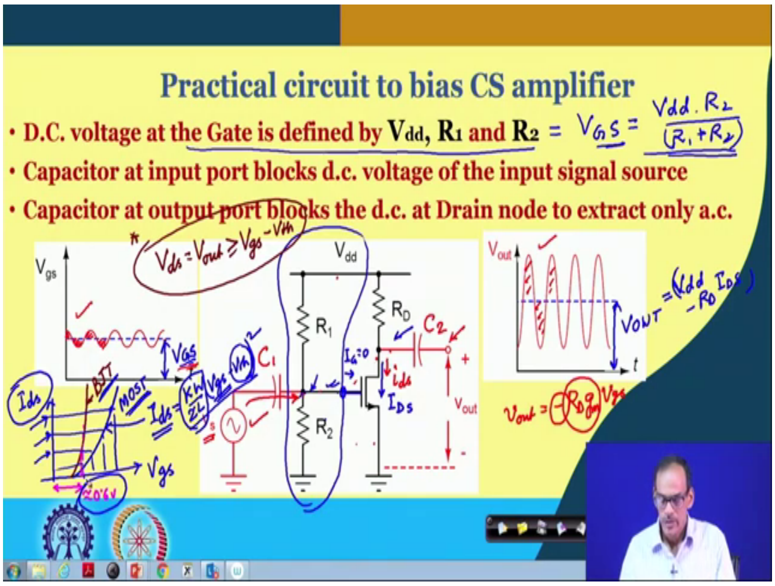

Practical circuit to bias CS amplifier

- D.C. voltage at the Gate is defined by V_{dd}, R_1 and R_2 = $V_{GS} = \frac{V_{dd} \cdot R_2}{(R_1 + R_2)}$
- Capacitor at input port blocks d.c. voltage of the input signal source
- Capacitor at output port blocks the d.c. at Drain node to extract only a.c.

So, now let us move to the practical circuit as I said. Before we go into the small signal analysis let me talk about the DC analysis part. So, as you can see here the DC voltage; DC voltage here it is generated by this V DD and the potential divider constructed by R 1 and R 2. So, I should say that this gate voltage or gate to source voltage now V GS earlier we are talking about V GS equals to V DD multiplied by R 2 divided by R 1 plus R 2 alright.

So, that is the DC voltage we are applying here. So, that is this voltage capital V capital GS. And then we need to be it is important to make a note that unlike V gt the voltage here it is remaining unchanged even if you connect the transistor there unlike V gt where the base current it was there and then we are ignoring the base current compared to the main current main the current flowing through the bias circuit.

However, in this case this gate current anyway it is 0, so I capital G it is 0. So, even if you connect the transistor the voltage at this point DC voltage at this point remains the same as whatever it is given by this expression. And then once we have the DC voltage we do have a signal coming to this gate through this capacitor.

So, this C 1 signal coupling capacitor C 1 it is allowing the signal coming to the gate and if the signal frequency and this R C time constant it is satisfying a condition. So, we can say that this most of the signal it is directly coming to the gate and making this V GS fluctuating over this DC or I should say that small signal part it is riding over the DC part.

So, with this arrangement we are making the series connection of the signal and the DC voltage here. Now, with this V GS of course, the DC and AC combination it is producing the small signal current here and i ds as I said before in the previous slide discussion in addition to we do have capital I DS and the voltage here as I said that it is having a DC part which is V DD minus R D into I DS.

So, this is the V OUT part V capital OUT. So, that is equal to V dd minus R D into I capital DS and then on top of that we do have does the signal; we do have the small signal. So, we do have the small signal riding over this DC and then this small signal it is as we have discussed before that v small out equals to minus R D into gm into v gs.

So, note that this provides amplification and then also it is having a minus sign. So, input here and output here they do have 180 degree phase difference and then of course, it is having a gain and we assume that while the signal it is riding over the DC the transistor here it is remaining in saturation region namely the condition to keep the device in saturation which is V ds or capital V out it is higher than V gs minus V th. So, that is the assumption ok.

So, at this output now to suppress the DC part what we are doing here it is we are putting the other capacitor C 2 and then we are removing the DC part and then we are extracting the signal part at this point right. So, that is the circuit here. Now, if we consider the small signal part if we like to draw the DC part in our analysis we have to make this is AC ground yeah and yeah.

So, we will be discussing that, but here in comparison with BJT I must see one important thing that in MOSFET I ds versus V gs capital I ds versus V gs characteristic curve it is it is a squared law right unlike BJT, where the BJT on the other hand it was very sharp it was exponential. So, this is BJTs characteristic curve and the blue one it is MOSFET.

So, what is the main important point we must convey here it is that for BJT even if you consider say wide range of the current the corresponding voltage from ammeter to sorry base to emit a voltage it is approximately equal to say 0.6 or 0.7 volt what do you call V B1.

On the other hand if I consider the MOSFET we do have depending on different values of currents here the corresponding V gs it is quite different. So, the voltage here since we are making this biasing by voltage the corresponding voltage should be such that the required currents are obtained. So, the DC voltage at the gate for the MOSFET and the corresponding targets current the DC current is very important.

So, we need to frequently use this square law equation for this characteristic curve namely I ds equals to K W by L W by 2 L rather V gs minus V th squared. So, this equation you have to use. So, the procedure here it is that if you have a target value of this current and then if you know this parameter or transconductance factor and then also the V th from that we have to calculate we have to back calculate rather required V gs and then you can find the voltage here.

Will discuss this one in the numerical example again, but that is the basic difference between the biasing of common emitter amplifier versus common source amplifier. For common source amplifier we have to use this square law again and again whereas, for BJT only V B on is good enough all right, so ok. So, we are talking about the small signal equivalent circuit of the practical circuit shown here.

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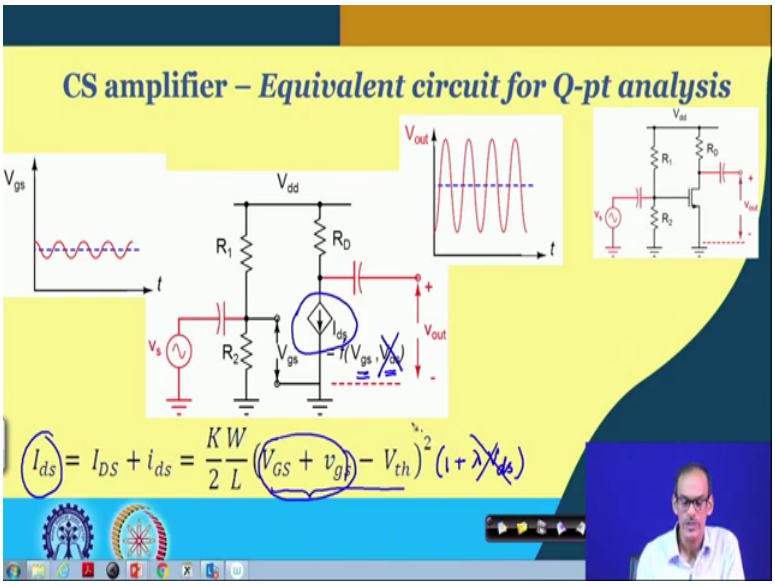

CS amplifier – *Equivalent circuit for Q-pt analysis*

$$\boxed{I_{ds}} = I_{DS} + i_{ds} = \frac{K}{2}\frac{W}{L}\left(\underbrace{V_{GS} + v_{gs}}_{} - V_{th}\right)^2 (1 + \lambda \cancel{V_{ds}})$$

So, before sorry most of the discussion probably which we have done just now we already have yeah we do have the slide for the discussion, but again I like to say that this expression of this I ds it is having the explicit expression or in terms of V gs and the this equation; this equation is getting represented by this voltage dependent current source. It is in fact, function of V gs my and also the V ds, but then V ds dependency it is only through 1 plus lambda V ds part and typically we drop this part considering this is approximately 1.

So, we may say that I ds is function of V gs and the V gs it is having a DC part and the small signal part and so this equation we frequently use. So, the previous circuit and the previous circuit so what we have considered the practical circuit.

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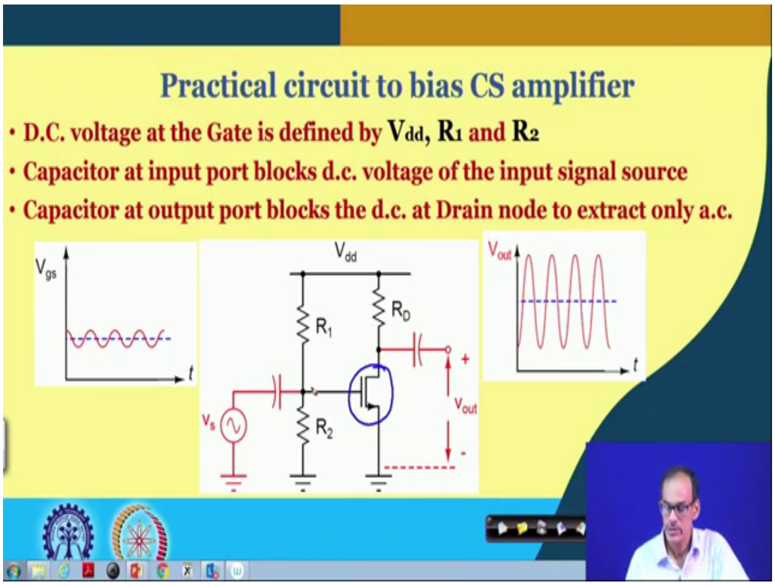

Practical circuit to bias CS amplifier

- D.C. voltage at the Gate is defined by V_{dd}, R_1 and R_2
- Capacitor at input port blocks d.c. voltage of the input signal source
- Capacitor at output port blocks the d.c. at Drain node to extract only a.c.

And so this circuit when will be analyzing we need to replace the device. We need to replace the device by yeah we need to replace this divide by it is equivalent model and in the equivalent model what we mean is that this I ds; I ds function of the V gs

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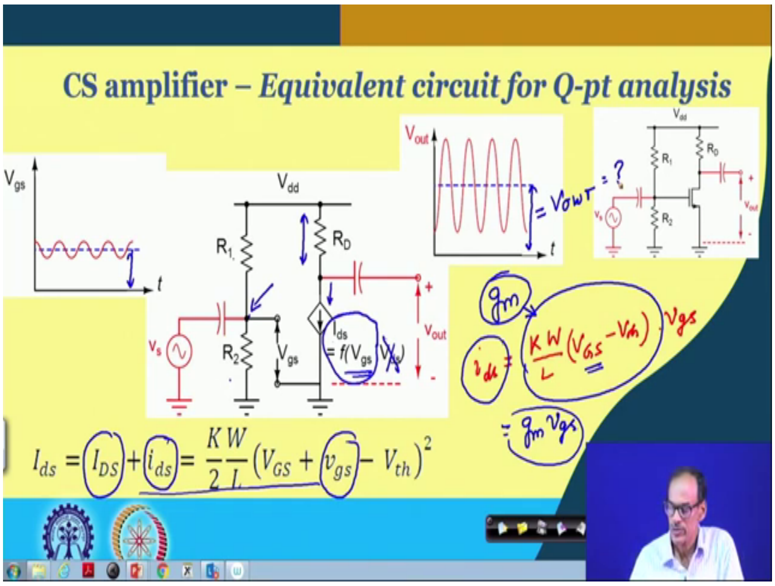

CS amplifier – *Equivalent circuit for Q-pt analysis*

$$I_{ds} = \boxed{I_{DS}} + \boxed{i_{ds}} = \frac{K}{2}\frac{W}{L}\left(V_{GS} + \boxed{v_{gs}} - V_{th}\right)^2$$

g_m

$$i_{ds} = \boxed{\frac{KW}{L}\left(V_{GS} - V_{th}\right)} v_{gs}$$

$$= g_m v_{gs}$$

So, this I ds is function of the V gs and this equation and then rest of the things we already have discussed that DC part here and then the DC part here how do you calculate and then we find the relationship between I ds small i ds and then V gs.

So, what we have here it is i ds equals to K W by L V GS minus V th into v gs and what we said it is this part it is the g m part. So, we said that i ds equals to gm into V gs. In fact, if you look into the detail expression of this part after ignoring this part it is as you say that it is having a DC current and these small signal current and the small signal current expression is given here. And in that expression g m it is very important and it is expression of course, it is function of the equation point namely it is depends on the DC condition there.

Now, this circuit this equivalent circuit of course, it is it can be used for operating point and if we have the value of this V dd and then R 1 and R 2 from that you can find the DC voltage here. And then you can find the corresponding DC current here and from that DC current you can find what will be the corresponding drop here and then from that you can find what will be the V OUT part V capital OUT part. In addition to that the same equivalent circuit it can be mapped into small signal also and in the small signal what you do it is simply we consider; we consider this is AC ground.

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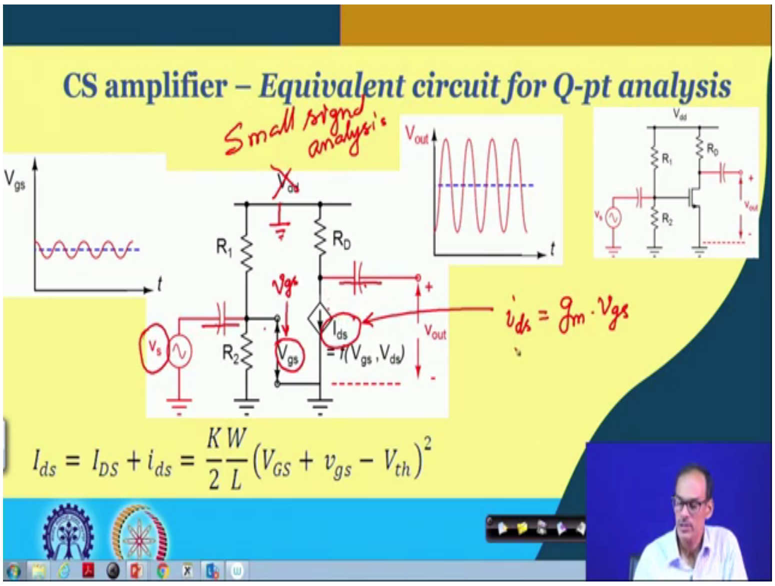

CS amplifier – *Equivalent circuit for Q-pt analysis*

Small signal analysis

$i_{ds} = g_m \cdot v_{gs}$

$$I_{ds} = I_{DS} + i_{ds} = \frac{K}{2}\frac{W}{L}(V_{GS} + v_{gs} - V_{th})^2$$

So, in small signal; in small signal analysis what you do? We denote this DC part we make it ground and then we short these 2 capacitors and then this part we removed the DC part and then we take only the small signal part i ds which is g m times v gs and the v gs is the voltage here. So, we are removing the DC part we are replacing this by small v gs and this v gs it is incidentally same as this v s assuming that this capacitor is working as a short.

So, by doing this conversion namely the capacitors into short circuit DC voltage to be 0 DC current and we are getting the corresponding small signal equivalent circuit. So, in the next slide will be showing that the small signal equivalent circuit ok. So, we will take a small break and then we will come back with this small signal equivalent circuit analysis.